



Document No.

2001-05-01.V2

LAPP Mechanical department

writer

Franck CADOUX

Date : 30-07-01

AMS-02 group - ELECTROMAGNETIC CALORIMETER -

STUDY OF MAGNETIC BEHAVIOUR FOR A MATRIX OF SHIELDING

Abstract

The aim of this note is to present both calculations and tests performed on a matrix of 1mm thick shielding tubes according to different configurations in order to validate several parameters: material and dimensions.

All the tests were decided after our first calculations performed on the large matrix of ECAL predicted a geometry effect reducing the efficiency of shielding.

Prepared by :

CADOUX Franck

LAPP- Service mécanique

Cadoux@lapp.in2p3.fr

Checked by :

Jean-Pierre VIALLE

Roman KOSSAKOWSKI

Approved by:

Jean-Pierre VIALLE

History of Changes

<i>Rev. No.</i>	<i>Date</i>	<i>Pages</i>	<i>Description of Changes</i>
------------------------	--------------------	---------------------	--------------------------------------

- Table of contents -

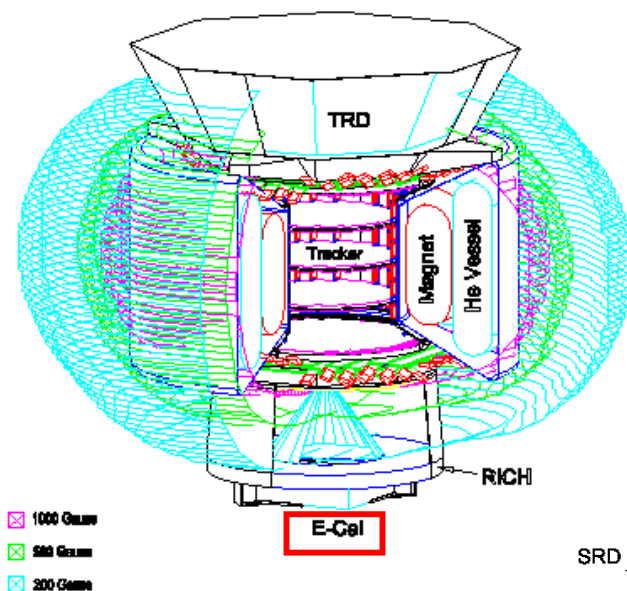
1. PRESENTATION.....	4
1.1 AMS2 STRAY FIELD AND ECAL POSITION	4
1.2 ECAL DESIGN	5
2. PRELIMINARY STUDY ON A SINGLE SHIELDING TUBE.....	6
2.1 PRESENTATION	6
2.2 COIL CALIBRATION	7
2.3 TESTS AND CALCULATIONS WITH A SINGLE SHIELDING TUBE	7
3. STUDIES ON DIFFERENT MATRIX OF SHIELDING.....	10
3.1 PRESENTATION	10
3.2 PRELIMINARY STUDY	11
3.3 STUDY ON A “6X2 MATRIX”	12
3.3.1 <i>scheme of the study</i>	12
3.3.2 <i>saturation curves on X direction</i>	13
3.3.3 <i>saturation curves on Y direction</i>	13
3.3.4 <i>saturation curves on Z direction</i>	14
3.4 CONCLUSIONS ON A “6X2 MATRIX” BEHAVIOUR.....	15
3.5 STUDY ON A “3X4 MATRIX”	15
3.5.1 <i>scheme of the study</i>	15
3.5.2 <i>saturation curves on X direction</i>	16
3.5.3 <i>saturation curves on y direction</i>	17
3.5.4 <i>saturation curves on z direction</i>	17
3.5.5 <i>conclusions on 3x4 matrix</i>	18
3.5.6 <i>conclusions on the behaviour of both matrixes</i>	18
3.6 COMPACT CONFIGURATION	19
3.6.1 <i>scheme of the study</i>	19
3.6.2 <i>saturation curves on BX</i>	19
3.6.3 <i>saturation curves on BZ</i>	20
3.6.4 <i>conclusions on air gap effect</i>	20
3.7 GENERAL CONCLUSION ON THE BEHAVIOUR OF SMALL MATRIX.....	21
4. SIMULATIONS ON “5X18 MATRIX” – ECAL CONFIGURATION.....	22
4.1 POSITION OF THE PROBLEM	22
4.2 SCHEME OF THE STUDY AND FINITE ELEMENT MODEL	22
4.3 RESULTS OF SIMULATIONS	23
4.3.1 <i>results of BX case</i>	23
4.3.2 <i>saturation curves on BY</i>	24
4.3.3 <i>saturation curves on BZ</i>	25
4.4 CONCLUSIONS ON ECAL CONFIGURATION	25
4.5 COMPACT CONFIGURATION	26
4.6 SATURATION CURVE ON BX.....	26
4.7 FINAL CONCLUSIONS	26

1. PRESENTATION

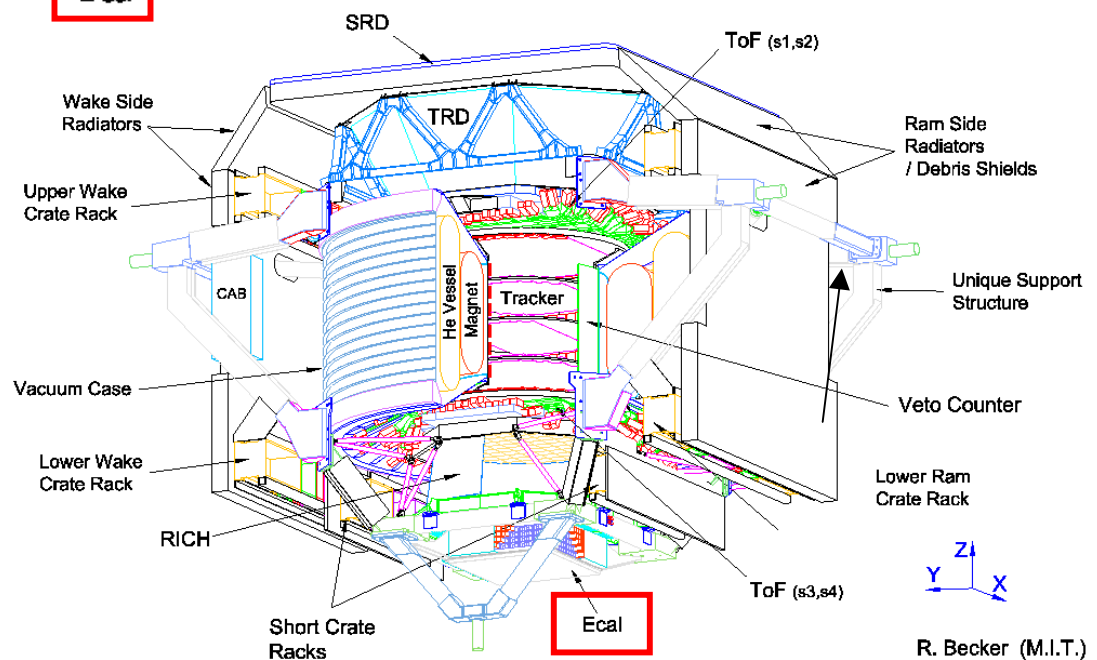
Due to the stray field at the ECAL position and to PM sensitivity, we need to study carefully the magnetic shielding in order to protect all the PM. We started the finite elements analysis (F.E.A.) on the subject at the beginning of April 2000 at LAPP by using the software SYSMAGNA.

1.1 AMS2 STRAY FIELD AND ECAL POSITION

Below are shown the magnetic field created by AMS 2 supra conductive magnet and a view of the whole AMS2 experiment.

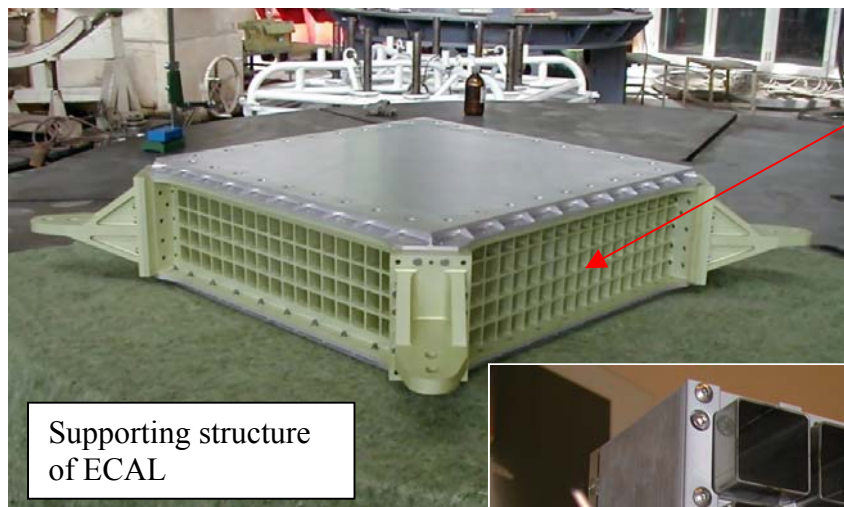


ECAL is positioned on the lower part of AMS2 experiment.
At this position, the magnetic field is between 100 and 200 Gauss.



R. Becker (M.I.T.)
February 21, 2001

1.2 ECAL DESIGN



Lateral panel

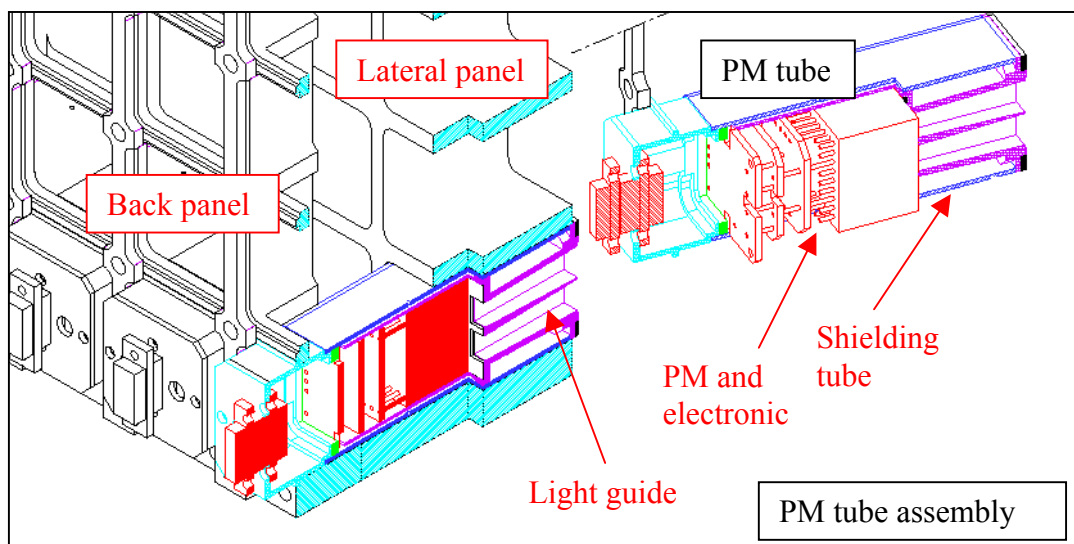
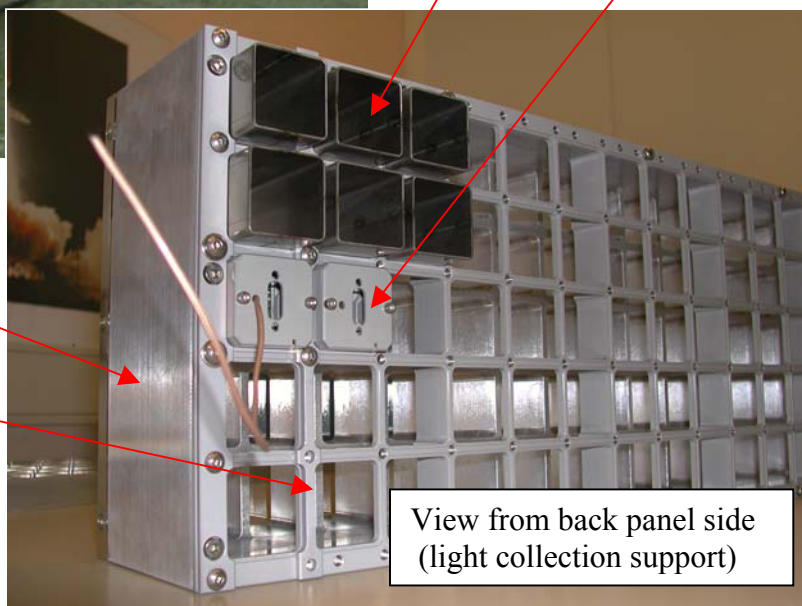
Shielding tube

PM tube with end cap

Lateral panel

Back panel

Note that each back panel is connected on lateral one.



NB: The four sides of ECAL have to be implemented with shielding tubes. This means that we will have four different matrixes of shielding (different orientations with respect to B field).

2. PRELIMINARY STUDY ON A SINGLE SHIELDING TUBE

2.1 PRESENTATION

The aim of these first tests is to check the magnetic performances of **Soft Iron**, the material we chose for shielding. This material is close to VACOFLUX50 performances used for AMS01 Cherenkov detector. See below the table of different materials for comparison :

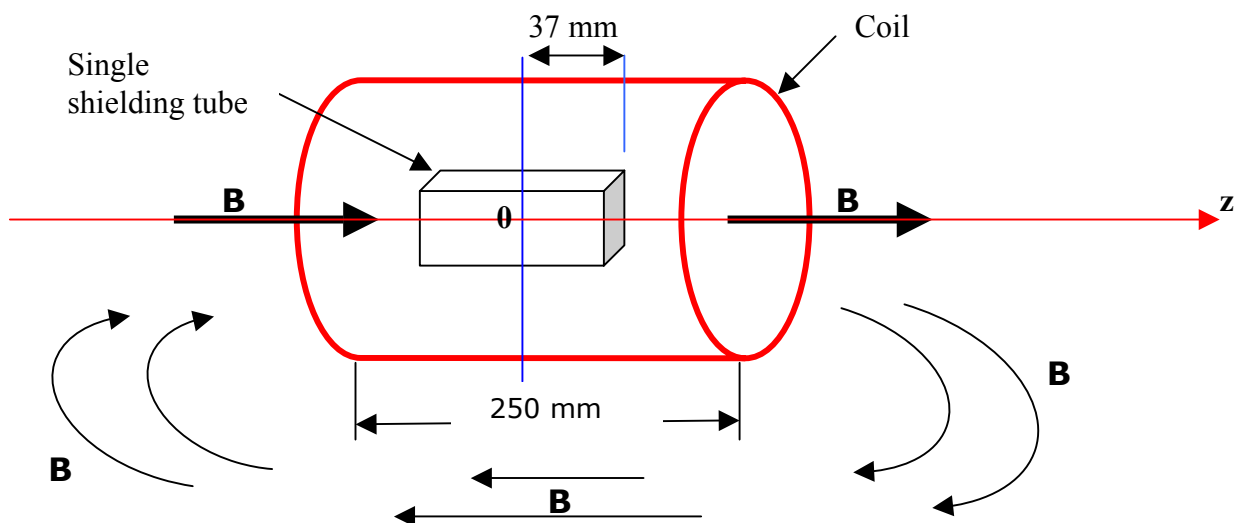
MATERIAL	Mumetal	Vacoflux 50 *	Soft Iron	Supra 36 *
Permea. μ_{\max}	100000	4000	6000	20000
$B_{\text{sat.}}$	0,8	2,35	2,15	1,3
Density	8,7	8,15	7,85	8,1

NB: For high external B_{field} , we use material with high $B_{\text{sat.}}$ like **SOFT IRON** or **VACOFLUX 50**. In case of low external B_{field} and if we search a negligible resulting B_{field} inside shielding tube, we will prefer **MUMETAL** or **Supra 36**. In addition, **VACOFLUX 50** and **Soft iron** have the same coercivity (80 A/m, not fundamental in our case).

* Note that **VACOFLUX 50** is a Co-Fe alloy, and **Supra 36** is a Fe-Ni alloy.

In the tests, we increase the magnetic field to such a level that we will see the saturation point of the shielding tube. We are interested in the magnetic field evolution along the tube axis with respect to the external B field. In order to underline different effects such as: edge effects, shielded length inside tube (PM position). It's also the way to fix some material parameters as B field saturation (B_{sat}), and permeability (μ) .

See below the scheme corresponding to the tests:



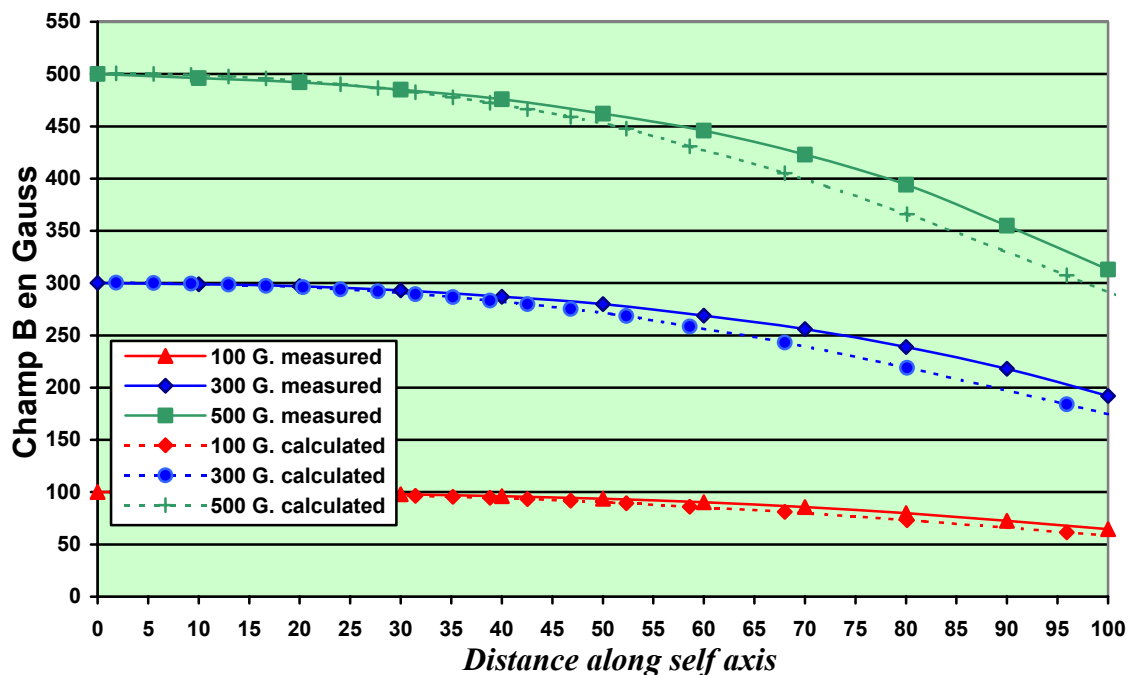
The confrontation between tests and simulation by finite elements analysis will allow us to validate some material parameters as B field saturation (B_{sat}), and permeability (μ). This is relevant before starting the calculations on a matrix of shielding tubes.

2.2 COIL CALIBRATION

The next graphs show the difference between the measurements done at LAPP by using a coil (see the graph next page) and the finite elements analysis performed with SYSMAGNA.

These curves represent the change of the magnetic field B from the axis toward the edge. For this first case, we don't take into account the shielding, we are only interested in the comparison between calculation and test considering the self itself. It's a way to calibrate our system for both calculations and tests.

- Measurements and calculations - B field curve

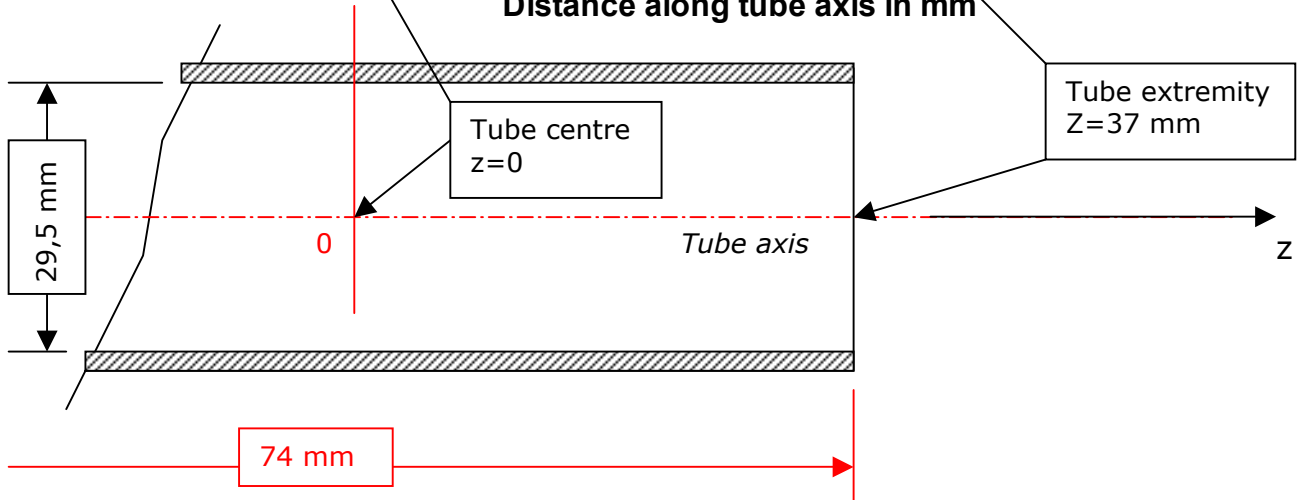
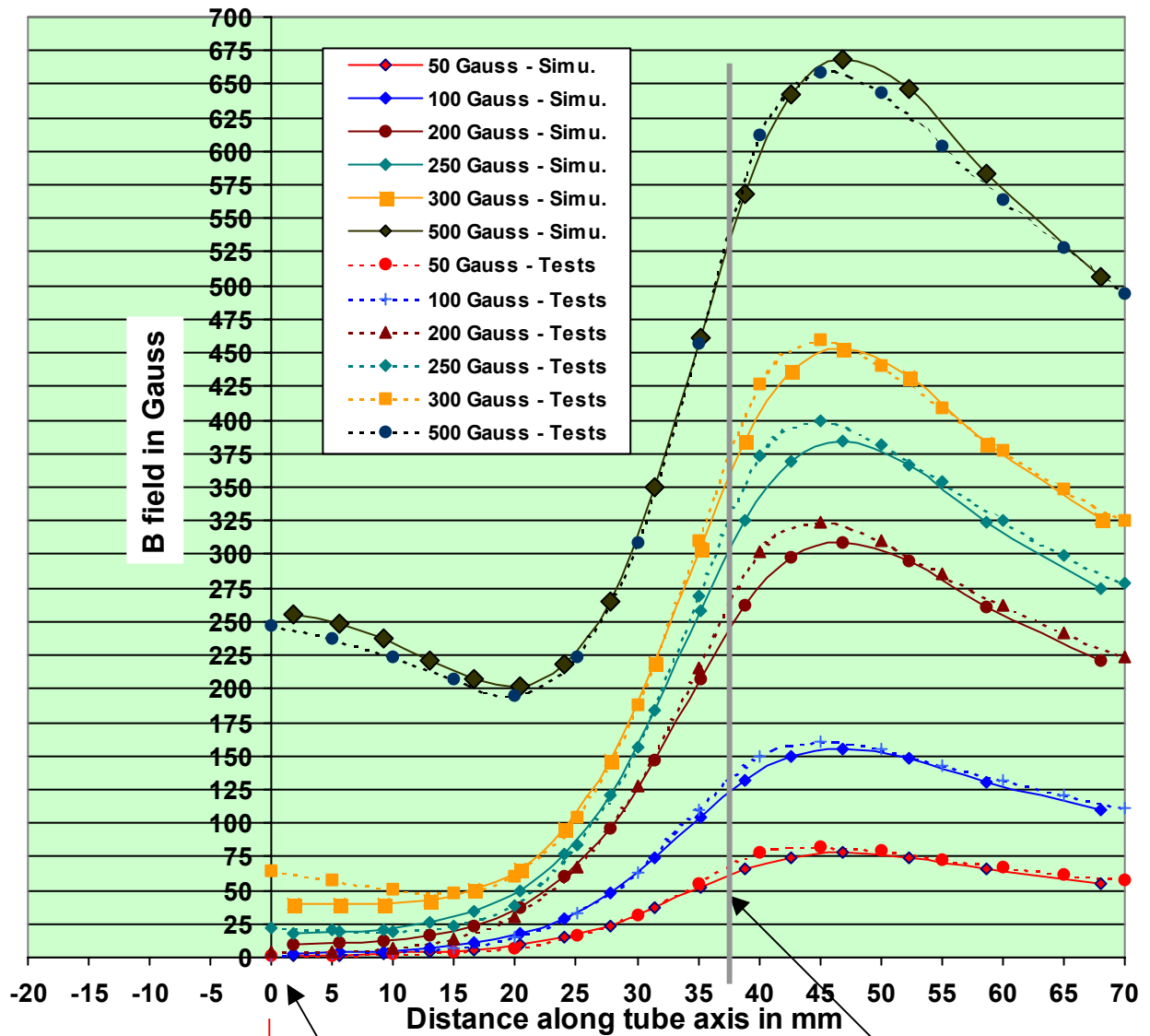


We can assume that the error on the “magnetic load” doesn't exceed 10 %. So, we are confident in our coil simulation. It's the started point before going on the simulations of 1mm thick shielding tube.

2.3 TESTS AND CALCULATIONS WITH A SINGLE SHIELDING TUBE

The aim of the test is to measure the residual field inside a shielding tube as a function of the external field, and to compare it to the calculation along the axis. We considered a symmetrical problem, that's why we show the measurements from the tube centre towards one edge only. The figure on the next page shows the results of the tests and of the simulations.

Attenuation curve along tube axis

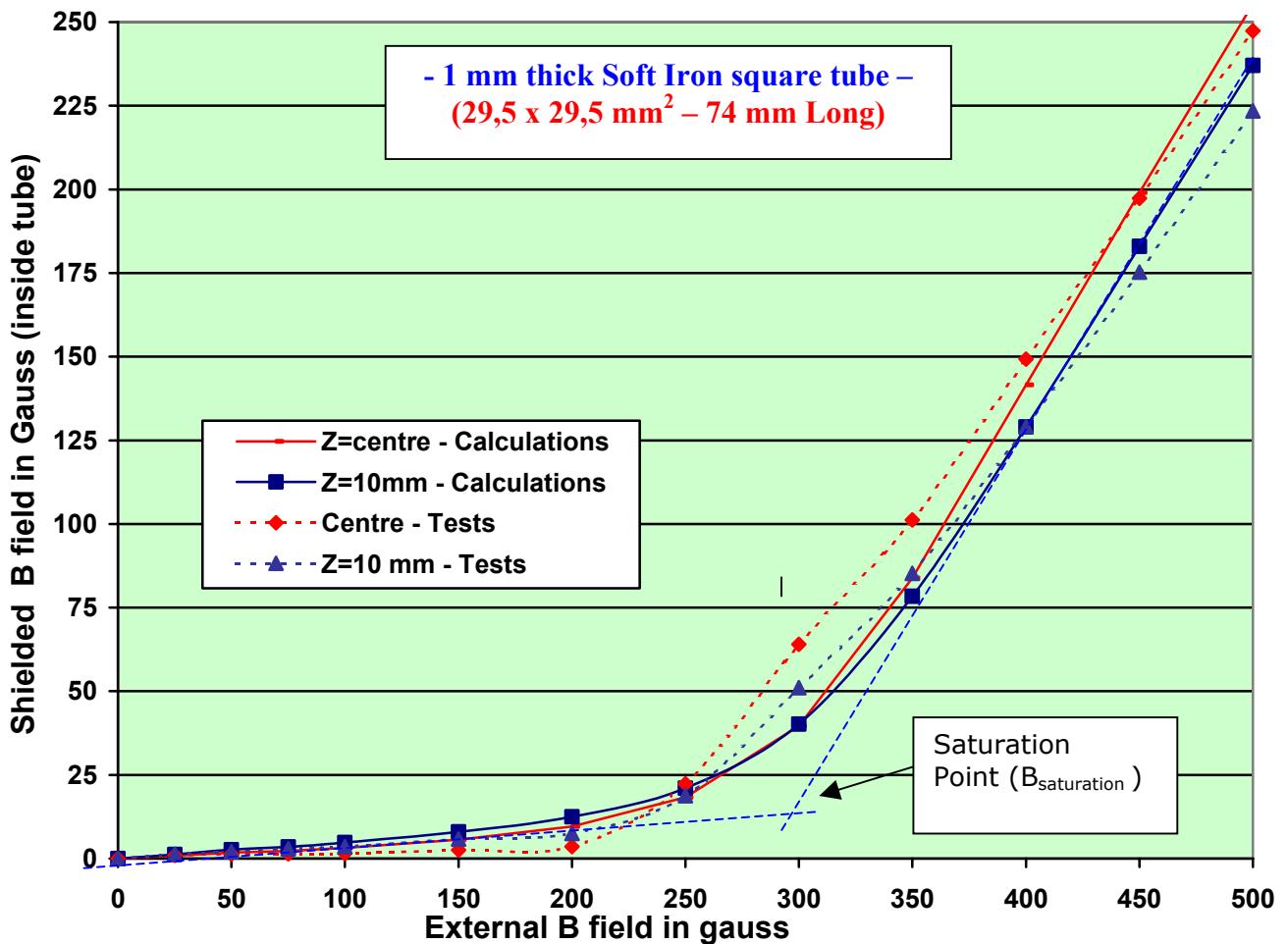


NB: Tests and calculations are close to each others. We see the same effect along tube axis (aperture effect). This means that FEA and material data used in FEA are close to reality.

On the next graph we are interested in the saturation curves. This means that for one point (one mesh in the FEA) we show the shielded B field (inside the tube) as a function of the external B field. That's a way to find what we call "**saturation point**". This point is characterised by two parameters: the value of external B field where the saturation occurs and the corresponding value of the residual B field in the tube centre.

The following graph shows two different points: the centre of tube and 10 mm from the centre. Concerning the studies on the matrix of shielding, we will focus on one point only: **the tube centre**.

- Saturation curves -



We found about 10 % difference between tests and calculations concerning the saturation point, it reflects both measurements and calculations uncertainties.

This is the kind of curves we will find in this document to get the two fundamental parameters: $B_{\text{saturation}}$, and $B_{\text{resulting}}$ at saturation.

To conclude, we find at the centre:

Tests: $B_{\text{sat.}} = 260 \text{ Gauss}$

Simulation: $B_{\text{sat.}} = 290 \text{ Gauss}$ (10% difference with tests)

3. STUDIES ON DIFFERENT MATRIX OF SHIELDING

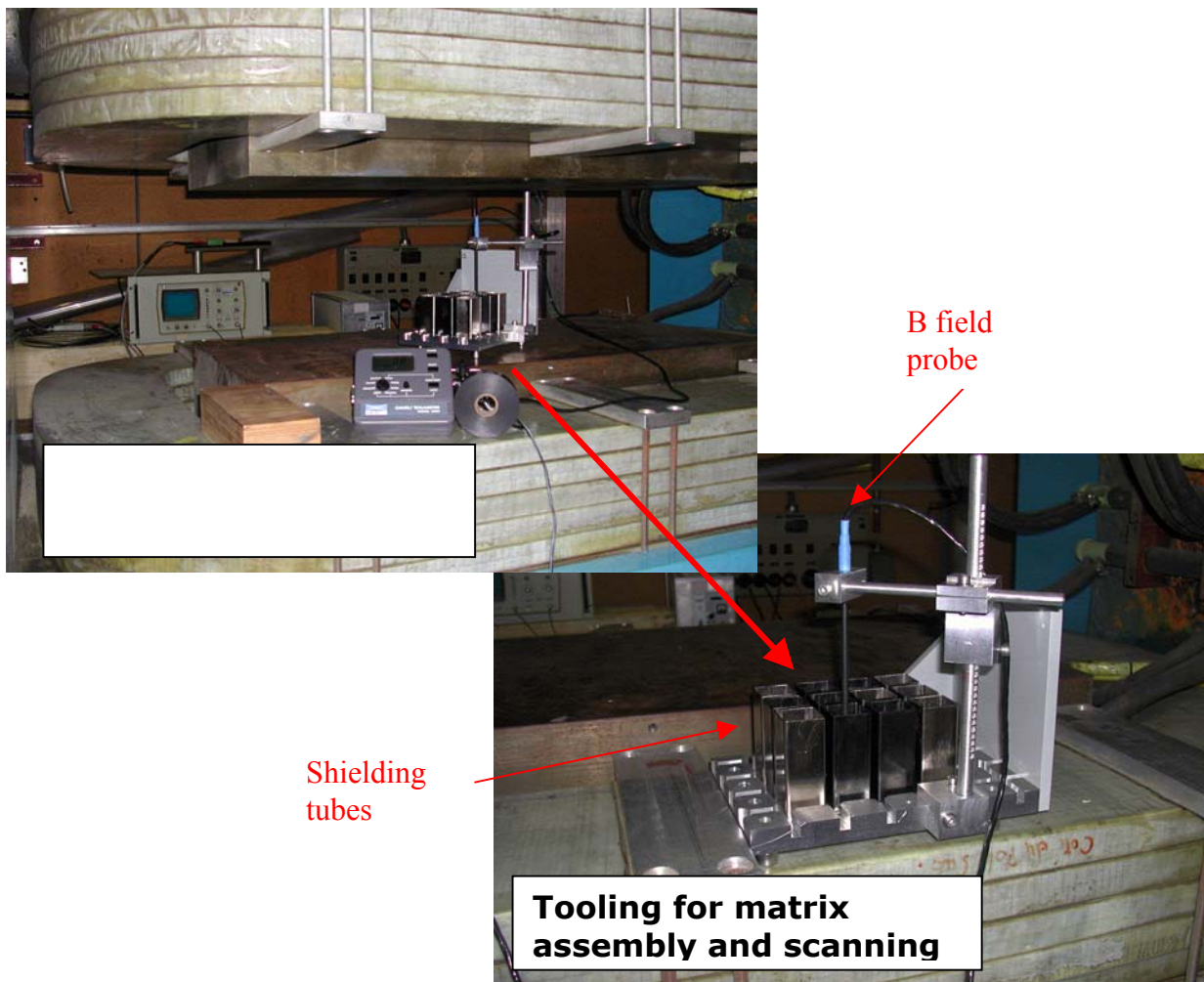
3.1 PRESENTATION

This paragraph presents a comparison between calculations and tests performed at CERN on different configurations of matrix. We ordered 12 shielding tubes, and we tested three configurations as follows:

- 6x2 matrix with 5 mm air gap between tubes (EMC configuration),
- 3x4 matrix with 5 mm air gap between tubes (EMC configuration),
- 3x4 matrix without air gap (similar to Rich configuration).

As in the last study, we used **1 mm thick shielding tubes** in “soft iron” (a 29,5 x 29,5 mm² square, and 74 mm long).

See below a few photos on the facility we used at CERN and the tooling built for the tests:

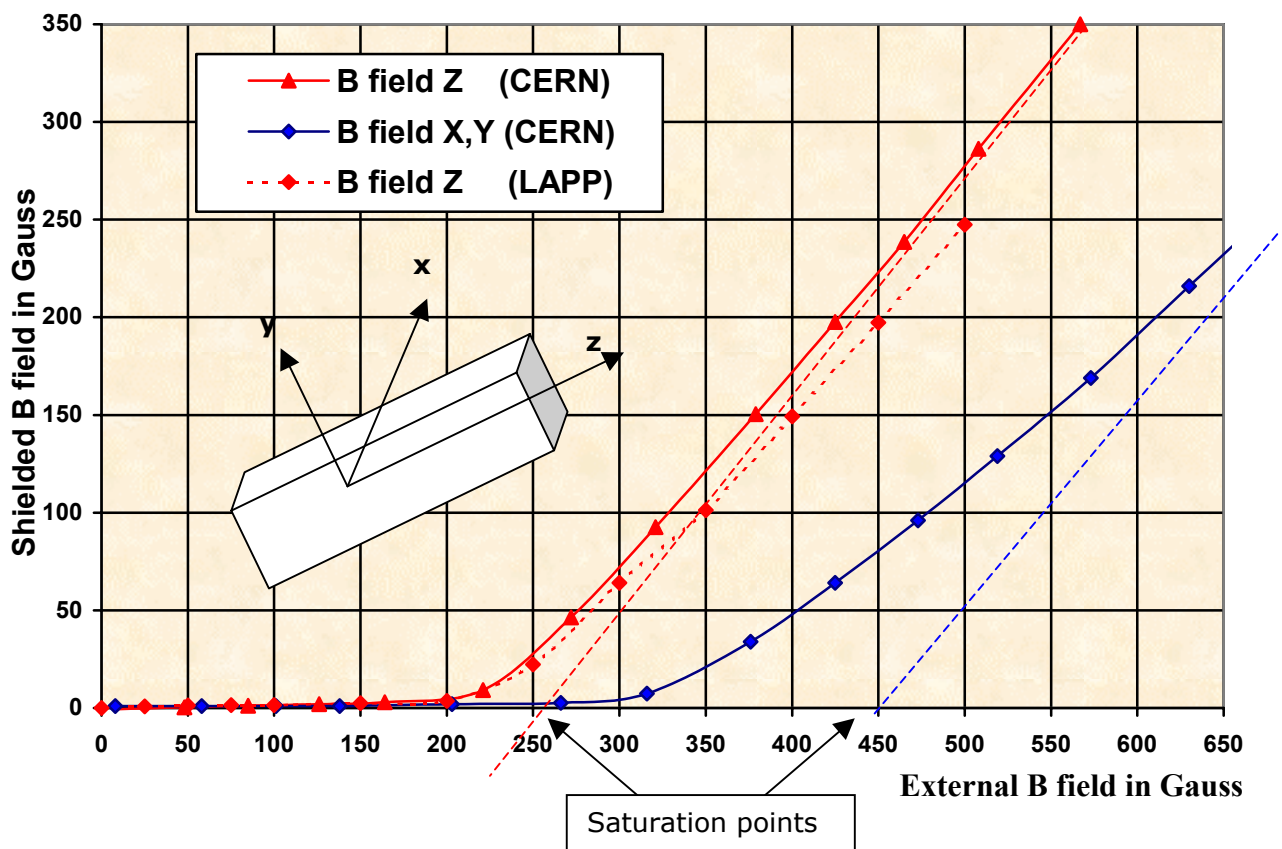


3.2 PRELIMINARY STUDY

As in the paragraph 1, we are interested in the tests on one **single tube**. With our equipment, we can test it in three directions: X,Y, and Z.

Below are shown the saturation curves at the tube centre for X/Y and Z directions. For Z direction, we compare the results coming from the first tests at LAPP and the one performed with the CERN facility.

- Saturation Curves



See the following table comparing two different directions X/Y and Z :

X or Y directions (transversal)	$B_{\text{saturation}} = 450 \text{ Gauss}$	(B resulting = 80 Gauss)
Z direction (along axis)	$B_{\text{saturation}} = 260 \text{ Gauss}$	(B resulting = 30 Gauss)

NB: On Z direction, both LAPP and CERN tests are close to each other.

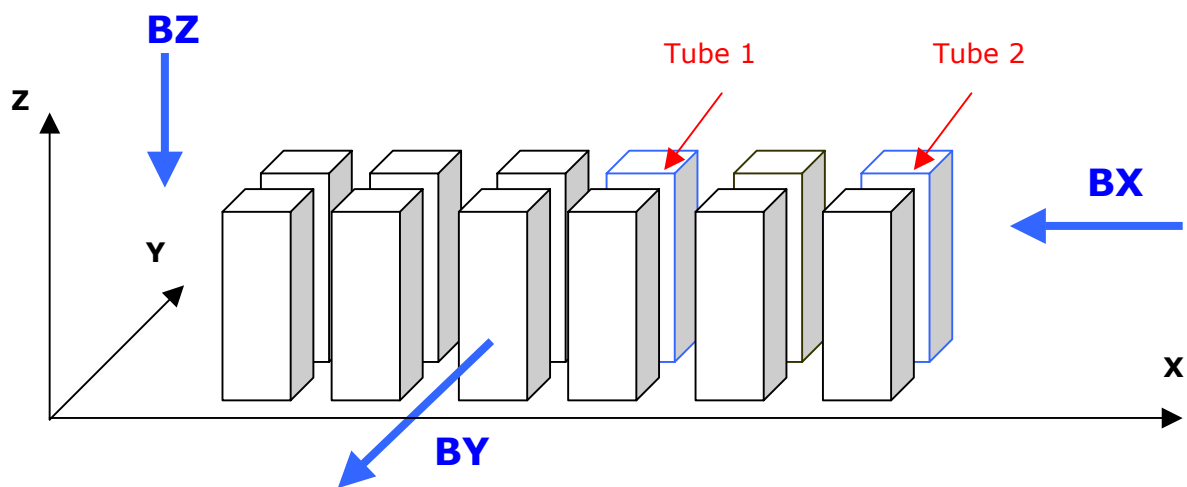
Conclusion:

X or Y direction has the best behaviour concerning saturation level. This confirms what is known on a **single tube**. When we take into account a **matrix of shielding tubes**, a new effect come into play due to the interaction between the stray field and the matrix of shielding.

The warning on this effect was given by our first calculations on a 5x18 matrix of shielding tubes. So we decided to test this effect as much as we can by using the CERN facility as shown in the last paragraph. We were limited by the size of the facility so we decided to test three different configurations with 12 tubes available.

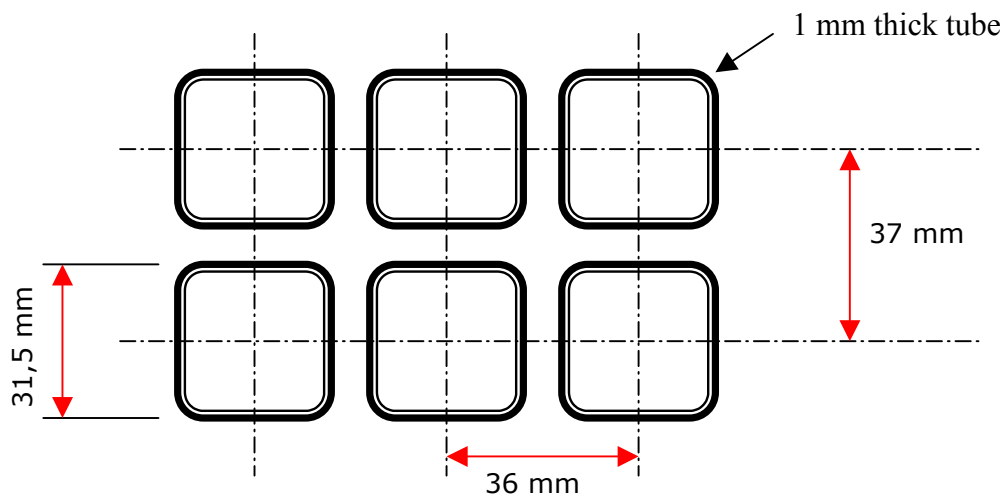
3.3 STUDY ON A “6X2 MATRIX”

3.3.1 SCHEME OF THE STUDY

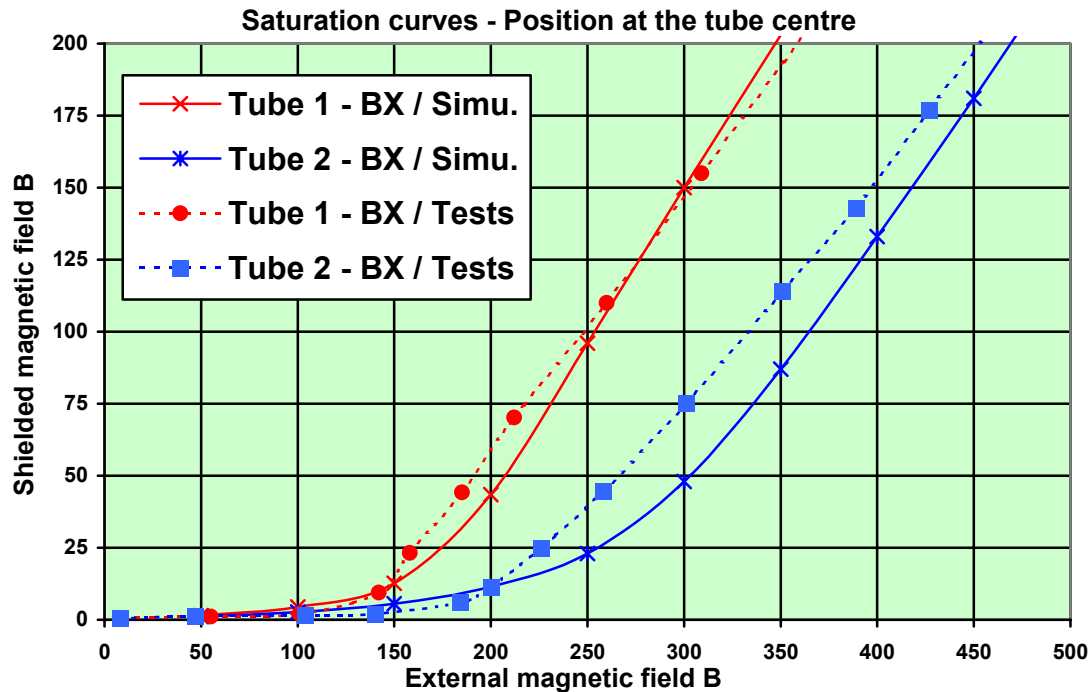


In this configuration we are only interested in the scanning of two tubes (at the centres) due to the symmetries of the problem. This allows us to test the magnetic behaviour of a “long” matrix of shielding tubes. Compared to a 3x4 matrix (X axis as long as Y axis, roughly speaking), this could underline the influence of geometry in the magnetic behaviour of a matrix.

Dimensioning:

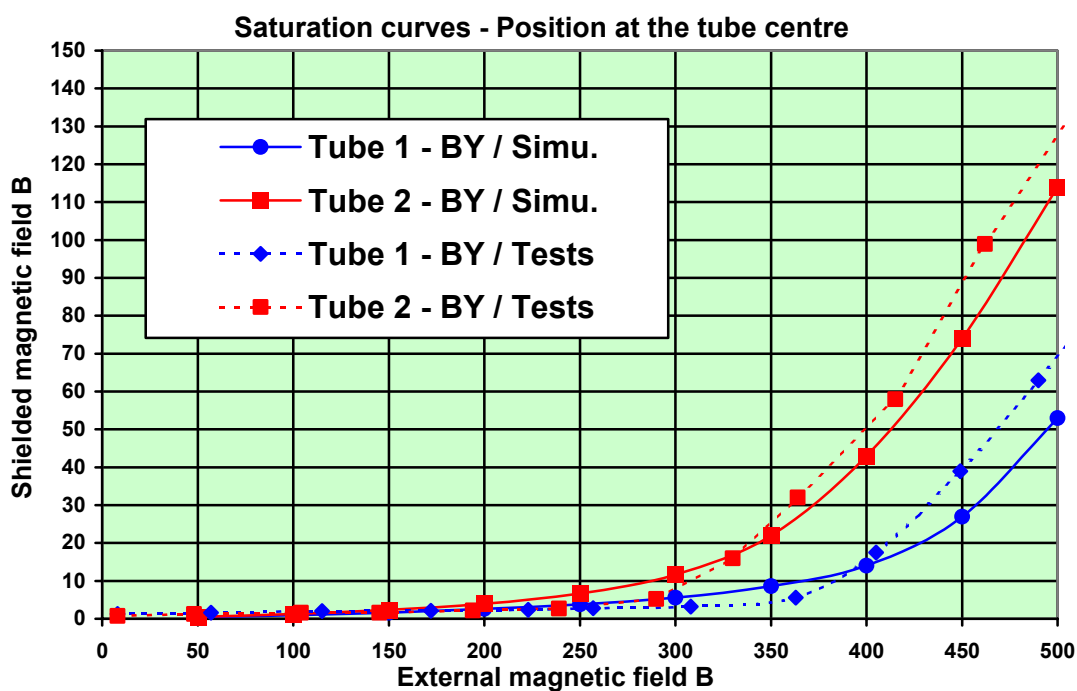


3.3.2 SATURATION CURVES ON X DIRECTION



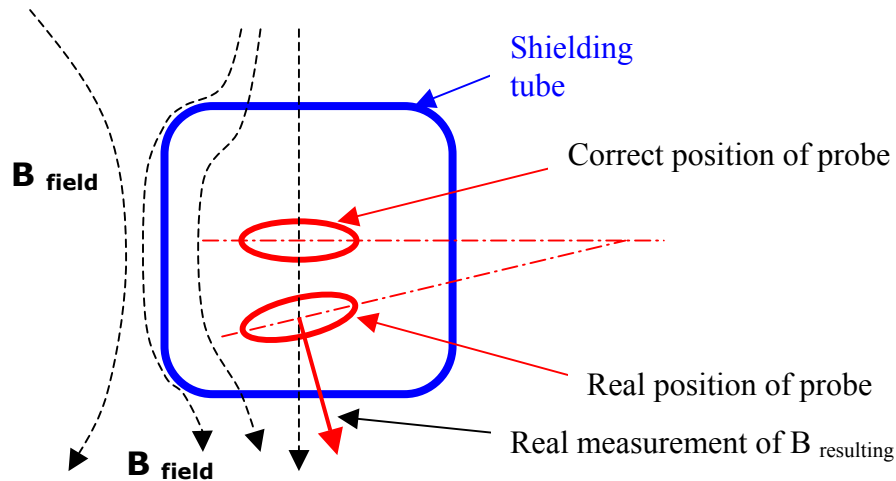
We note that we have a big difference between tube 1 and tube 2 on X direction: the residual field inside tube 1 is higher than tube 2.

3.3.3 SATURATION CURVES ON Y DIRECTION



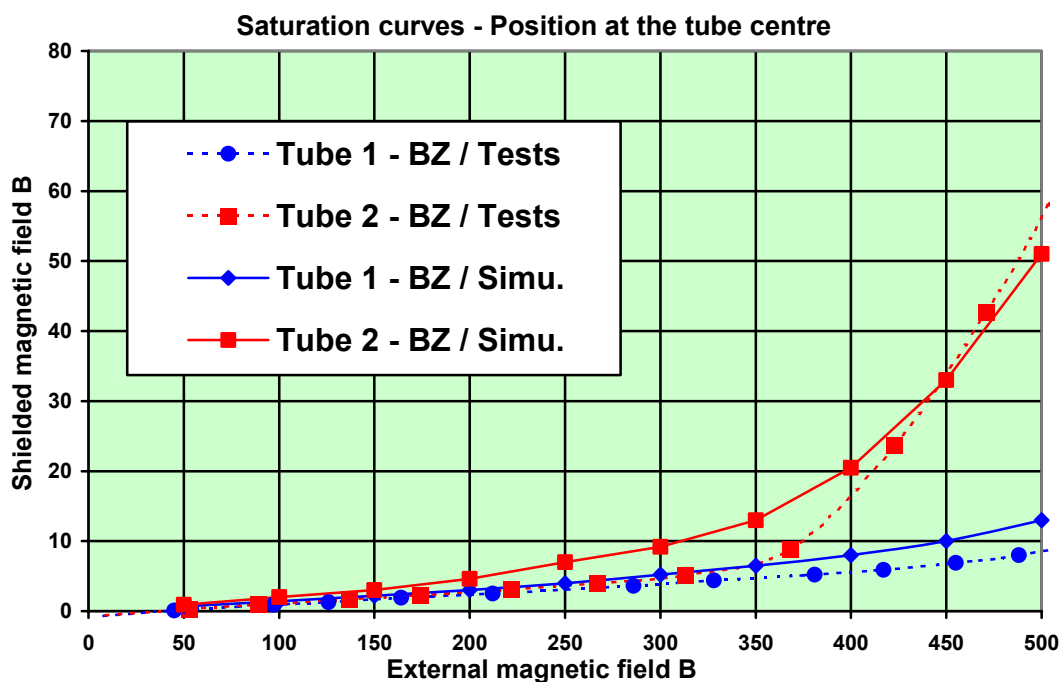
On Y direction the residual B field inside the tube 2 is higher than tube 1 (opposite behaviour to X direction).

A correction factor has to be applied to the measurements to take into account a bias in the positioning of the probe as shown below.



The **maximum correction factor** to be applied on the shielded B field is **10%**. This concerns only X and Y directions because we used a transversal probe sensitive to this position. On the last curves, no correction was applied to measured B field..

3.3.4 SATURATION CURVES ON Z DIRECTION



Comparison with simulations:

$B_{saturation}$ according to different axes (no correction factor applied to measured B field).

	TUBE 1			TUBE 2		
B_{sat}	BX_{sat}	BY_{sat}	BZ_{sat}	BX_{sat}	BY_{sat}	BZ_{sat}
Simulations	170	480	>500	275	410	> 500
Tests*	150	450	480	240	360	480
% differ.	12	7	17	13	12	15

The qualitative behaviour is the same as foreseen by simulations.

The quantitative aspect is satisfying (maximum difference below 20%).

For **Tube 1**, note that the ratio “BY over BX” (3 for tests and 2.85 for simulations) is the same as the one of matrix dimensions (Length X / Width Y = 3.08).

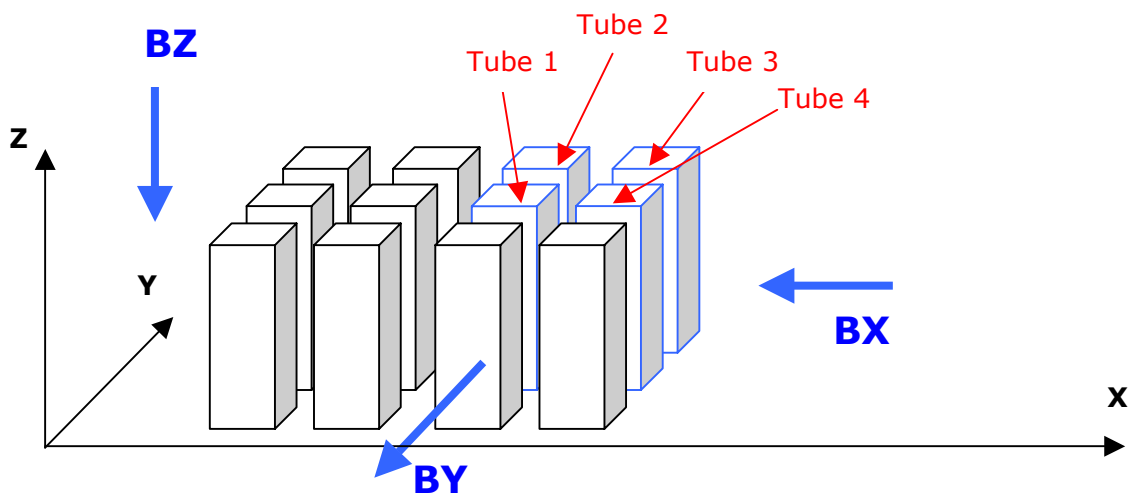
3.4 CONCLUSIONS ON A “6X2 MATRIX” BEHAVIOUR

First, the shielding is more efficient fore **BZ field**. Second, the shielding performances for **BX field** are strongly deteriorated for both tubes.

The residual field inside the central tubes of the matrix is higher than in the edge ones mainly in the X direction. It is due to the fact that the matrix of shielding gives a path to the lines of field in which they can flow more easily. This attraction of lines induces a concentration of field in this area.

3.5 STUDY ON A “3X4 MATRIX”

3.5.1 SCHEME OF THE STUDY

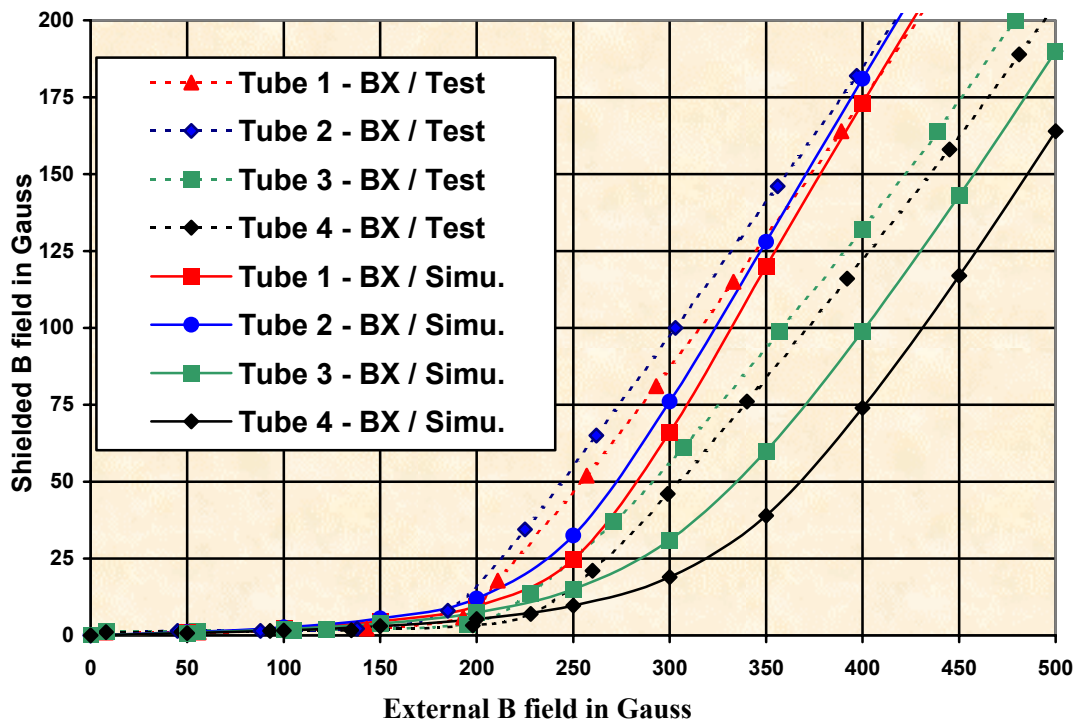


In this scheme we are interested in four different tubes (on only one quarter, due to symmetries).

As explained before, this 3x4 configuration allow us to see the influence of the geometry for a matrix of tubes by comparing with 6x2 configuration.

3.5.2 SATURATION CURVES ON X DIRECTION

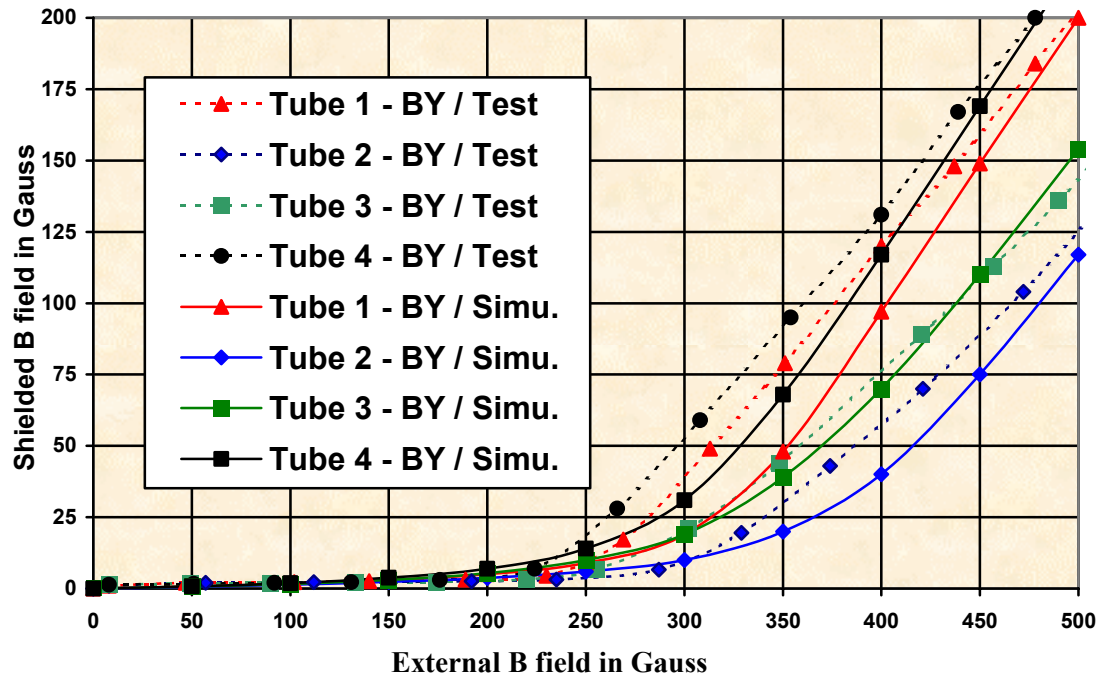
- *Saturation Curves*



NB : We can explain the difference between slopes coming from tests and calculations by the fact that we have to add 10% on the test values (means 10% more on slopes of the test curves).

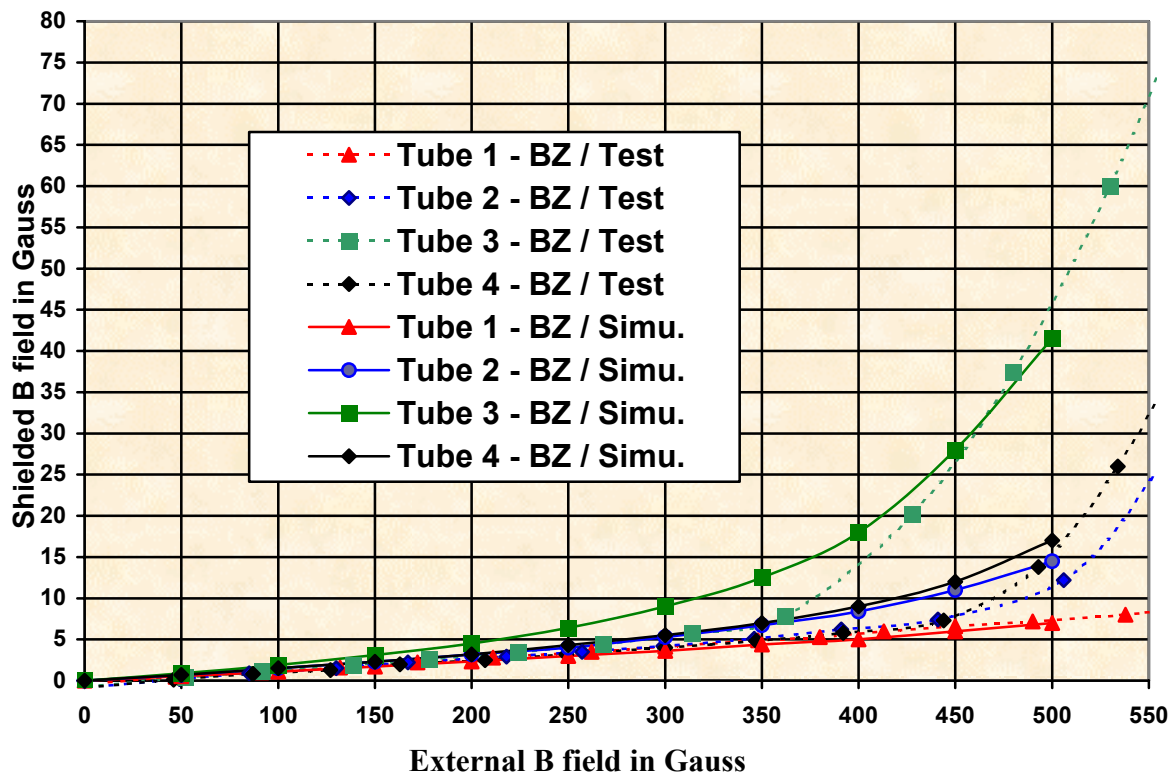
3.5.3 SATURATION CURVES ON Y DIRECTION

- Saturation Curves



3.5.4 SATURATION CURVES ON Z DIRECTION

- Saturation Curves



Comparison with simulations:

$B_{saturation}$ according to different axes (no correction factor applied to measured B field).

Comparison	TUBE 1			TUBE 3		
	BX sat	BY sat	BZ sat	BX sat	BY sat	BZ sat
Simulations	240	310	>550	300	325	≈500
Tests	220	260	>550	250	300	≈480
% differ.	9	16	0	17	8	-

We can underline the same behaviour as the 6x2 matrix which is the equivalence on the ratios of BY / BX (1.29) and Length / Width (1.32) only for tube 1. This is a geometry effect on matrixes.

3.5.5 CONCLUSIONS ON 3X4 MATRIX

The shielding on **BZ** is more efficient than on the other axes. Compared to the 6x2 matrix, we loose quality on **BY** shielding specially for central tubes.

3.5.6 CONCLUSIONS ON THE BEHAVIOUR OF BOTH MATRIXES

We find the same behaviour in 4x3 configuration as in 6x2 matrix concerning the saturation of central tubes with respect to edge ones on X direction. The following table comes from **tests only**.

Case	CENTRAL TUBE OF MATRIX			EDGE TUBES OF MATRIX		
	BX sat	BY sat	BZ sat	BX sat	BY sat	BZ sat
Single tube	450 G	450 G	260 G	-	-	-
Matrix 6x2	150 G	450 G	> 550 G	240 G	360 G	460 G
Matrix 3x4	210 G	260 G	> 550 G	260 G	300 G	360 G

Compared to the results coming from the preliminary study on a single tube, we can observe what we call a **matrix effect**, specially on the longest dimension (**X direction** in our study). This effect is amplified for the central tubes of any matrix (no effect on edge tubes).

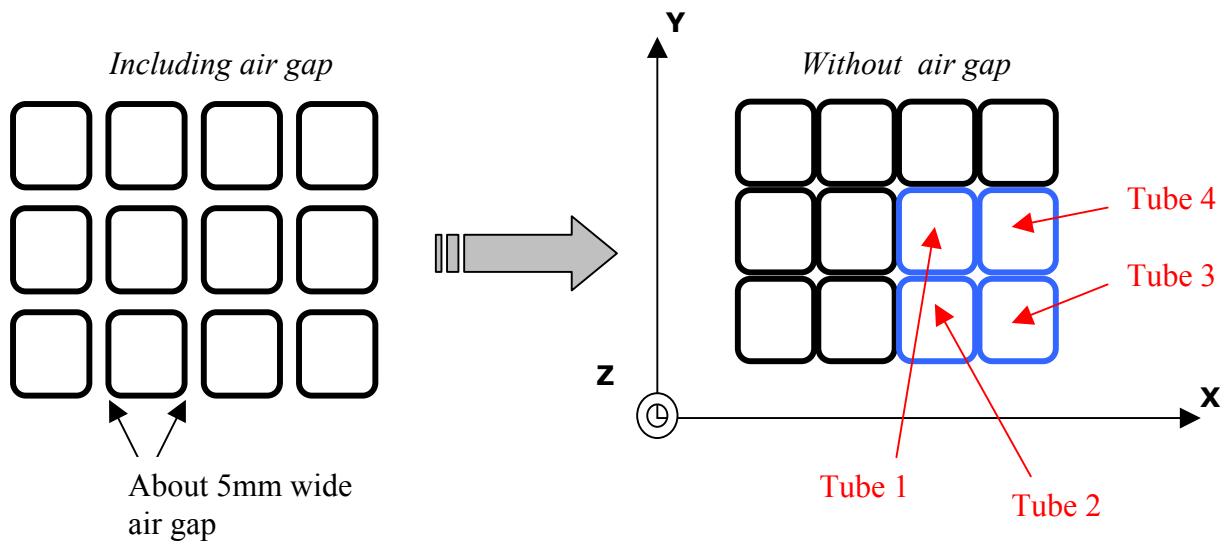
But on **Z direction**, the matrix configuration improves the magnetic behaviour (compared to the single tube).

The last relevant point for us is that the **simulation quality** is similar for both 6x2 and 3x4 configurations.

3.6 COMPACT CONFIGURATION

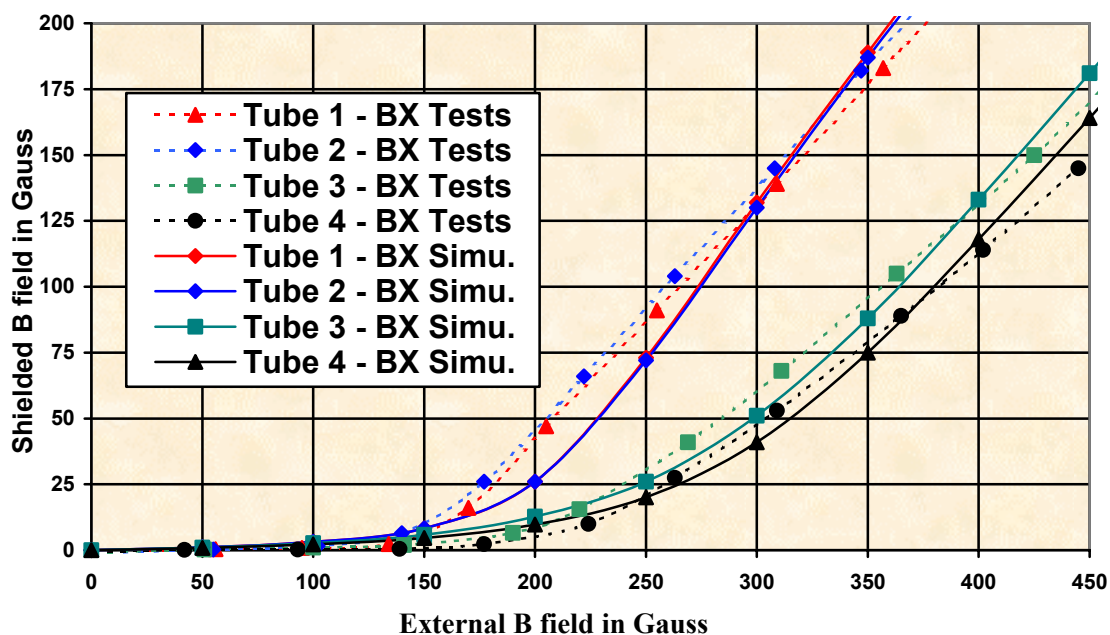
3.6.1 SCHEME OF THE STUDY

Compact configuration only means that we study the case of a matrix of shielding built without any air gap between each tube (contrary to EMC configuration). See below the scheme for more explanations:



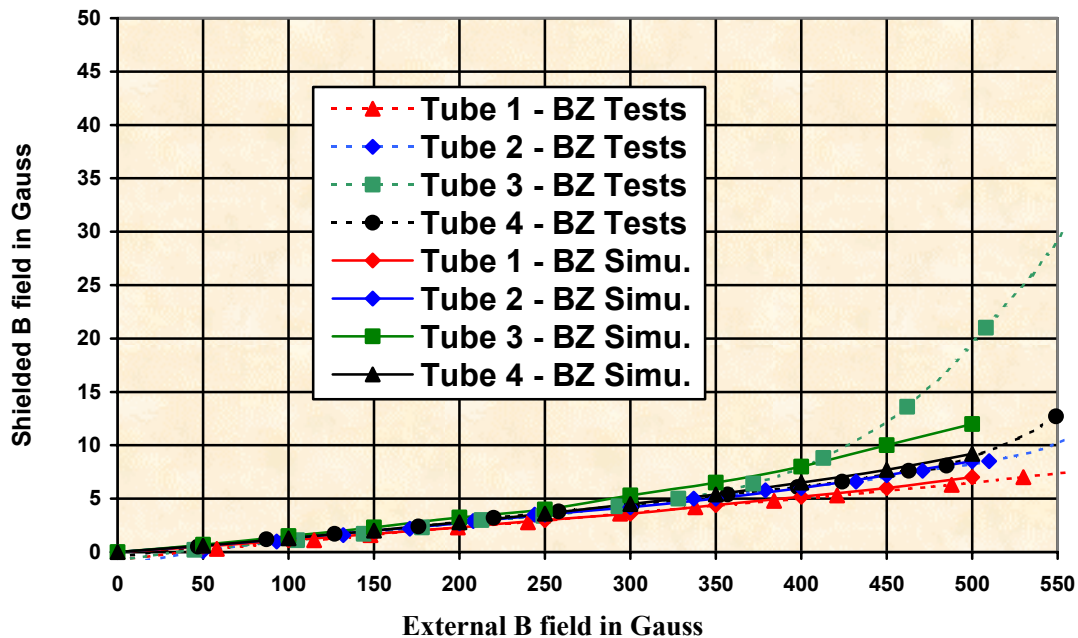
3.6.2 SATURATION CURVES ON BX

- Saturation Curves



3.6.3 SATURATION CURVES ON BZ

- Saturation Curves



3.6.4 CONCLUSIONS ON AIR GAP EFFECT

Table coming from tests:

Case	TUBE 1			TUBE 3		
	BX sat		BZ sat	BX sat		BZ sat
Matrix 3x4	220		>>550	250		≈480
Compact 3x4	160		>>550	250		>550
% difference	27		-	0		-

In any matrix, the lack of air gap between each tubes has a strange behaviour:

- Positive effect on **Z axis** (on **tube 3**, for 550 Gauss external, we reduce the shielded B_{field} from 70 Gauss to 30 Gauss!),
- Negative effect on **X axis** (we loose approximately **25%** for central tube concerning the saturation level between 5mm gap and no gap).

Both calculations and tests confirm this qualitative effect. This was confirmed by the tests performed by the RICH detector group.

3.7 GENERAL CONCLUSION ON THE BEHAVIOUR OF SMALL MATRIX

For each configuration, calculations by finite element analysis and tests are in good agreement. We observe the same effects, the numerical values are closer than 20% difference. So we can be confident for the next simulation of 5x18 matrix. For this matrix, only calculations are available.

We can give general ideas on matrix:

- Matrix has a negative effect on BX shielding in case of X greater than Y.
- Matrix improves magnetic shielding in Z direction (compared to a single tube).
- In a matrix, the air gap between tubes increases shielding efficiency in case of BX and BY. This has a relevant behaviour. The greater air gap is, the higher the saturation level will be for the central tubes. For BZ the shielding is improved in case of air gap reducing.

4. SIMULATIONS ON “5X18 MATRIX” – ECAL CONFIGURATION

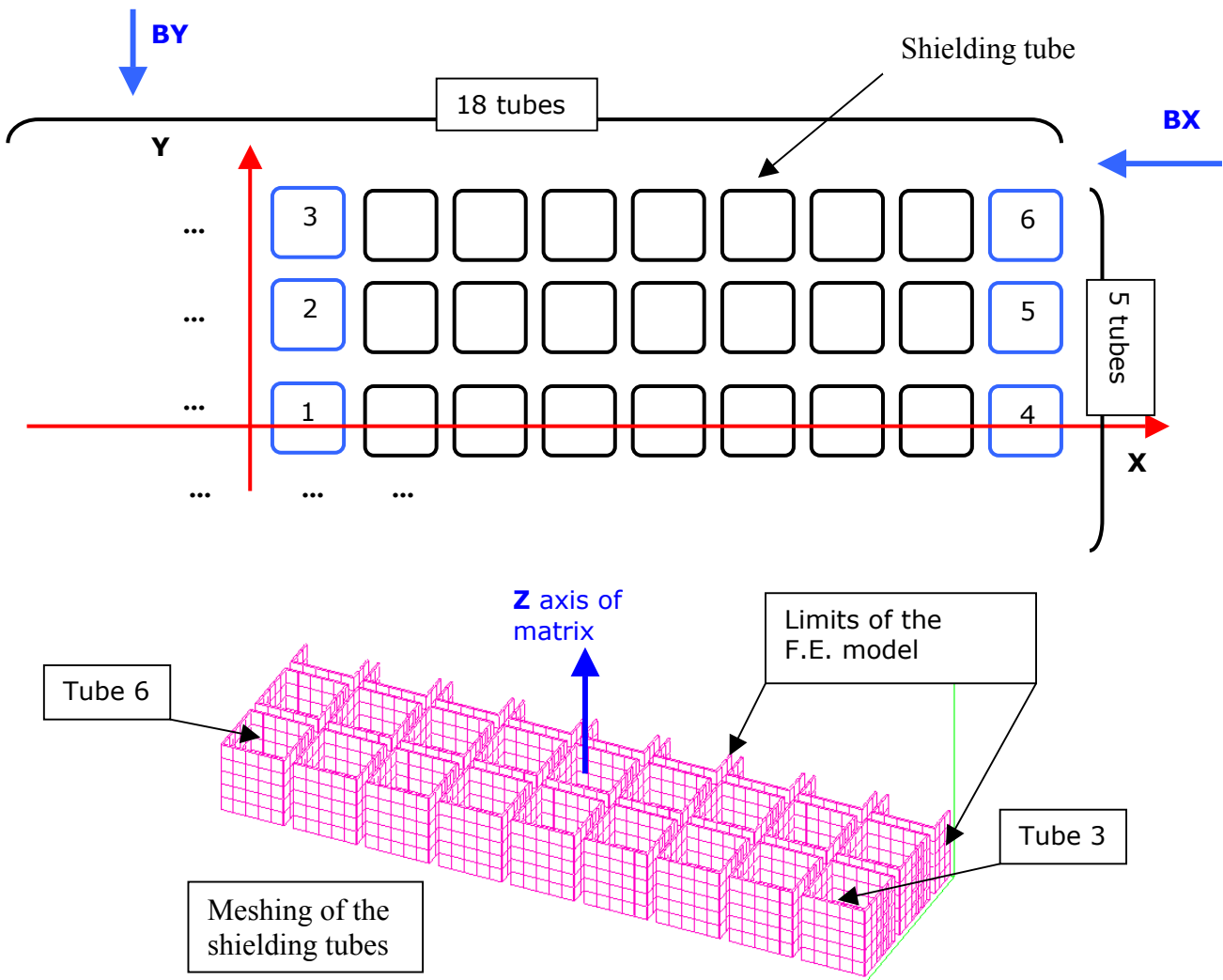
4.1 POSITION OF THE PROBLEM

Due to the fact that EMC needs to shield its 324 Pmt's (sensitive to the magnetic field) and after the preliminary simulations and measurements on single tube and small matrixes of tubes, we simulate a complete matrix of shielding tubes. It's a 5x18 configuration, corresponding to one side of ECAL (see paragraph 1 for more explanations).

4.2 SCHEME OF THE STUDY AND FINITE ELEMENT MODEL

For our Finite Element Analysis we considered only one quarter model, due to double symmetries. The total number and the arrangement of shielding tubes were done according to the ECAL side with 5 ranks of PM.

We are interested in 6 different tubes (extreme cases). See hereafter the drawing which represents the “5x18” matrix of shielding (one quarter model):



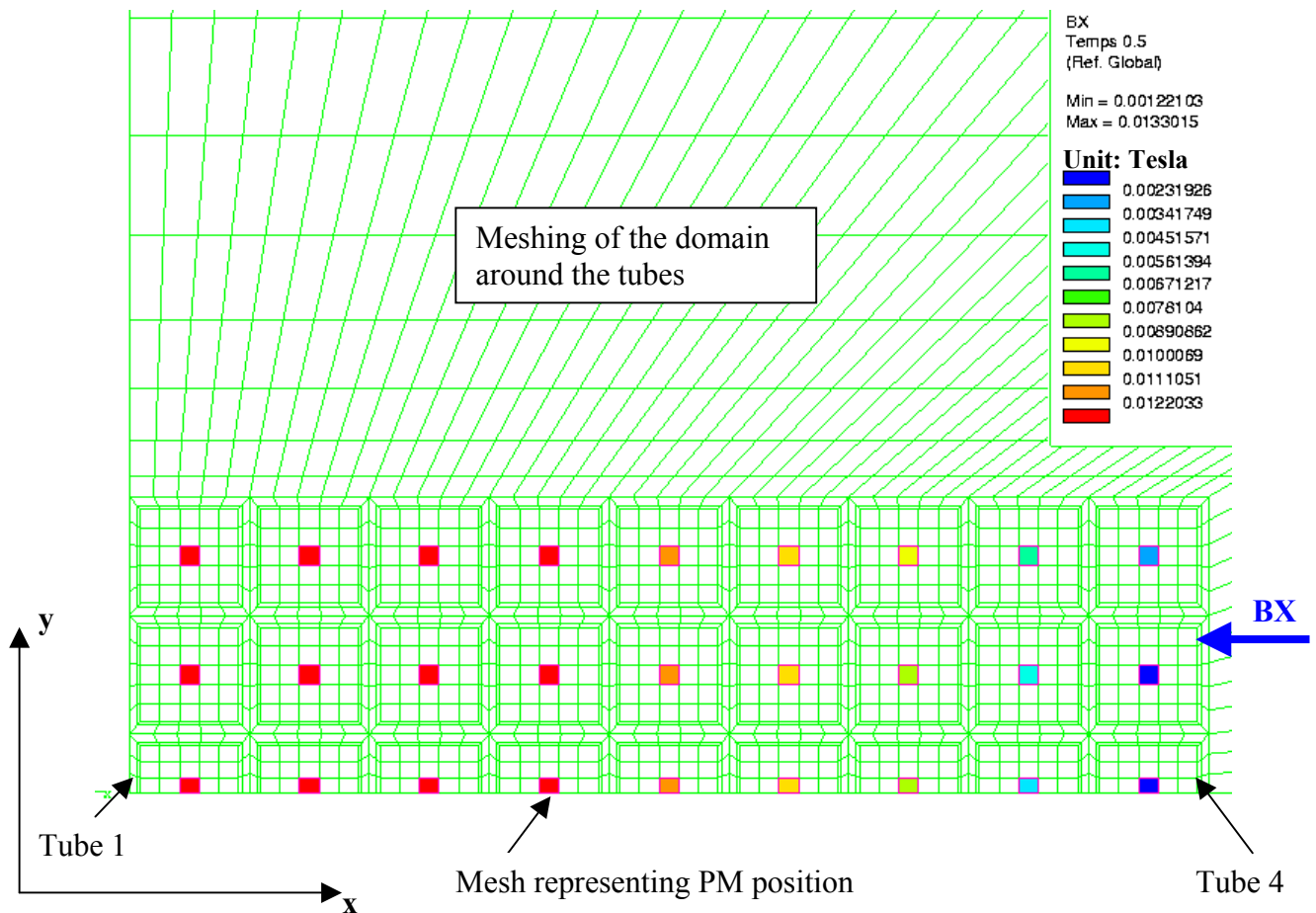
4.3 RESULTS OF SIMULATIONS

4.3.1 RESULTS OF BX CASE

A. Mapping of BX case

On the following map, all the results come from the centre of each shielding tube. In this case, the external B field is **250 Gauss** (saturation point reached).

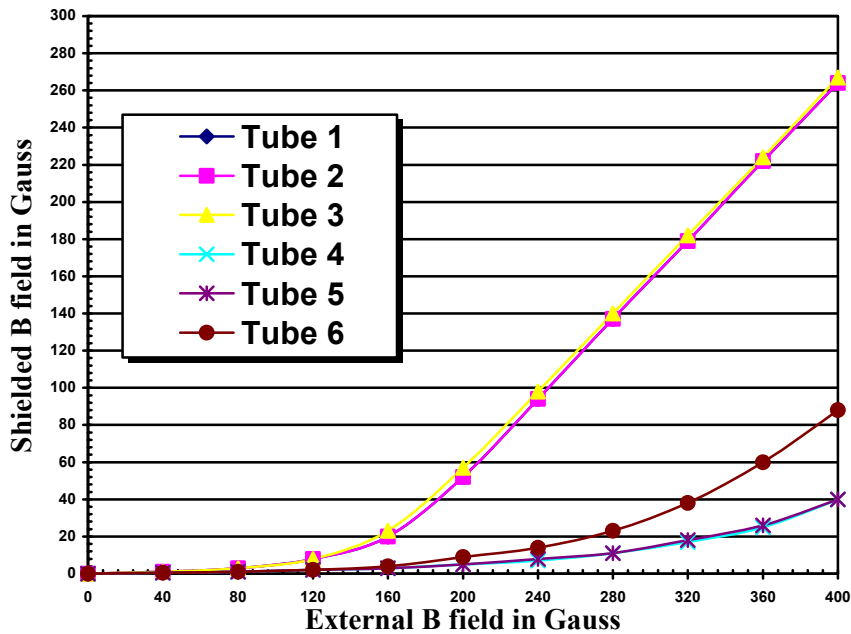
Below is shown the region where the resulting B field is predominant (from yellow to red colours). This concerns about 70% of all the tubes of the matrix.



Note that what we call edge effect concerns only the first tube columns perpendicular to the external B field direction (the same behaviour was observed for BY case).

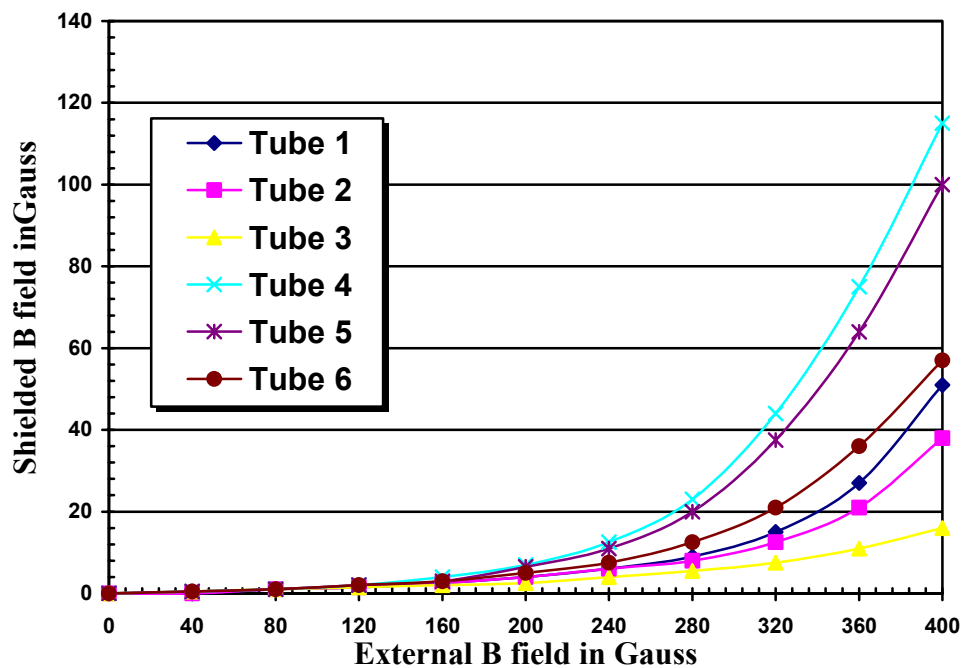
B. Saturation curves on BX

Saturation curves

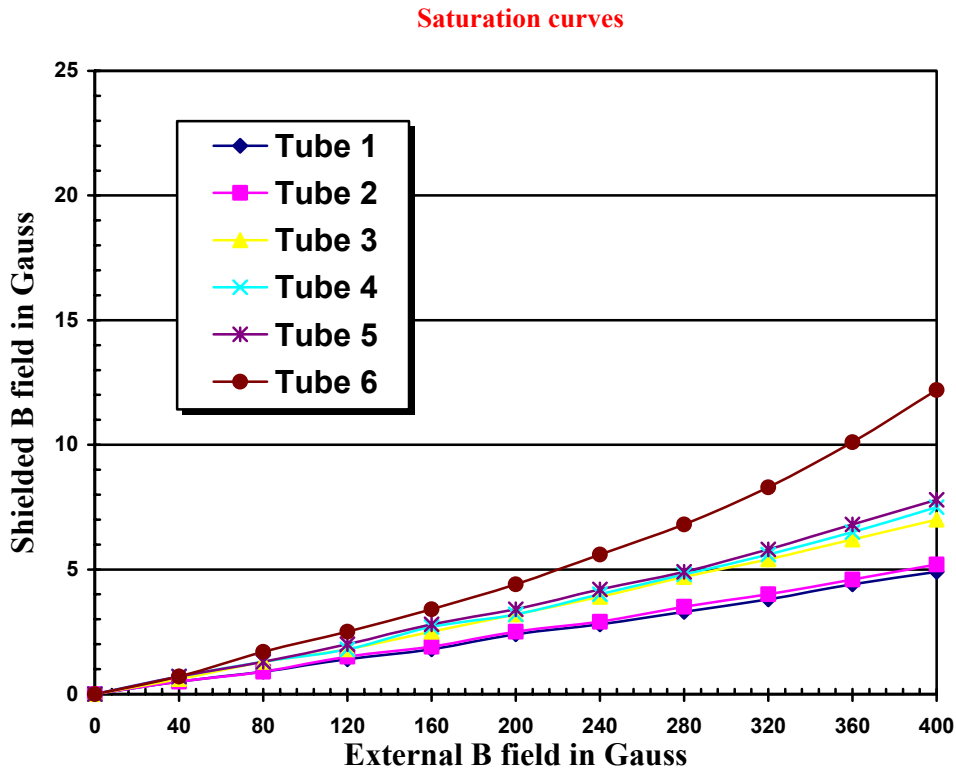


4.3.2 SATURATION CURVES ON BY

Saturation curves



4.3.3 SATURATION CURVES ON BZ



4.4 CONCLUSIONS ON ECAL CONFIGURATION

We use two extreme tubes in term of magnetic behaviour to summarise the study in the following table.

CASE	“Worst” tube position			“Best” tube position		
	X	Y	Z	X	Y	Z
B_{sat} in Gauss	160	370	>> 400	>400	300	>>400
Shielded B at 250 G	100	10	3	10	15	4

The only problem concerns the **BX** case for all the tubes on the centre of the matrix (we exclude only the tubes on the edges). At 250 Gauss we have a resulting field close to **100Gauss**. This concerns **all the tubes excluding the edges ones**.

We can talk about **an edge effect which improve the magnetic behaviour** for all the tubes on the edge (specially for BX). We increase the shielding on the edge due to the concentration of B field on the centre.

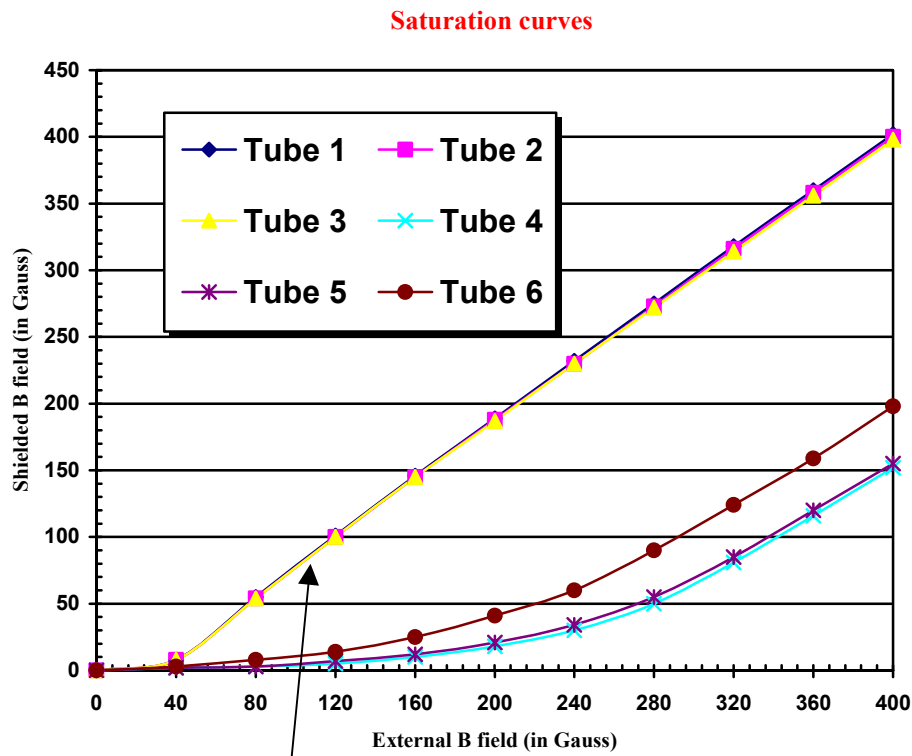
We have a good behaviour on other axes (low resulting B field) as expected by preliminary studies.

4.5 COMPACT CONFIGURATION

In this configuration the only calculation was done with 0.8 mm thick shielding tube. This refers to the configuration shown in paragraph 3.6.1.

4.6 SATURATION CURVE ON BX

We are only interested in X axis because as we know it's the worst case for the matrix.



The **lack of air gap** between tubes has a dramatic effect specially for the central tubes when we have a great matrix of shielding. For $B=250$ Gauss, the residual field in tube 1 remains 230 Gauss.

Calculations showed that the saturation level is dependent on the distance between tubes (air gap).

4.7 FINAL CONCLUSIONS

Due to the fact that PM have a different sensitivity on the three axis (one direction is much less sensitive than the others), we can give the following comments:

- **The least sensitive axis of each PM** has to be oriented on the longer axis of the matrix (X in our orientation).
- **For BZ case** we cannot orient PM as we want. But on Z, the magnetic behaviour of matrixes is very good.
- **For BX and BY cases**, the **air gap** between each tube of the matrix has to be maximised as much as possible: it's a relevant parameter in a matrix of shielding.